

**Measurements of Fixed Satellite Service (FSS) Earth Station  
Spillover Emissions to Evaluate Potential Interference Levels to  
Nearby 5G Systems Operating in the 28 GHz Frequency Band**

**September 29, 2016**

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## 1. Introduction

The goal of this testing is to assess the levels of maximum spillover and/or scattered power flux density from FSS Earth Station dish antennas at various distances and azimuth angles from the FSS sites.

A search of the FCC database, based on licensed FSS Earth Stations operating in the 27.5 to 30 GHz frequency range yielded a list of 50+ sites. From this list, eight sites were selected based upon location and viability of measurement accessibility as inferred from publicly available FSS Earth Station photographs. Sites were selected that were at ground level and generally free of nearby large reflective surfaces and foliage. Sites that were located on the tops of buildings or in congested downtown environments were not considered. The focus was to measure the emissions of established sites to obtain a real world assessment.

While eight sites were visited and surveyed, only five of the sites were actually accessible for measurement. Foliage, terrain and property access were major obstacles in these cases. The remaining five sites are listed in section 3.0 of the report. These sites were measured at various distances from the FSS dish antenna and at various angles to the transmit azimuth as allowable by the terrain. In each case, measurements were performed at four heights.

## 2. Test Specifications

### 2.1 Test Methodology

#### 2.1.1 Background

The spillover radiated power of a FSS earth station antenna is the RF power radiated in all angular regions outside the intended focal point. The Ka band FSS Earth Station Antennas (ESA) have a highly directional narrow beamwidth which requires precision pointing accuracy and high surface regularity for controlling both the main beam and spillover power levels. However over time, mechanical misalignments, lack of electrical tune-ups and environmental damages may cause these spillover levels to increase.

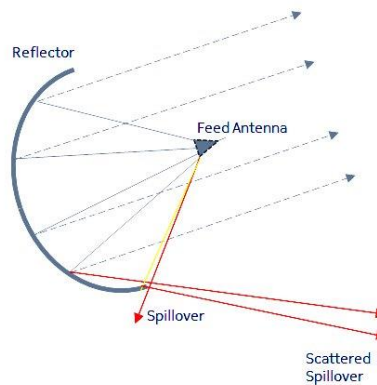


Figure 1: FSS Earth Station Antenna Spillover Radiation

Additionally, spillover may occur due to:

- Feed Horn energy which misses the reflector.
- Imperfections in the Feed-Reflector focus
- Phasing errors, i.e. real feeds vs. idealized point
- Reflector deviation from paraboloidal shape
- Blockages and reflections from feed support and secondary reflector support structure
- Random surface error
- Tradeoffs between size and desired efficiency
- Scattered energy from the feed support structure and imperfections are considered part of the total spillover for this discussion.

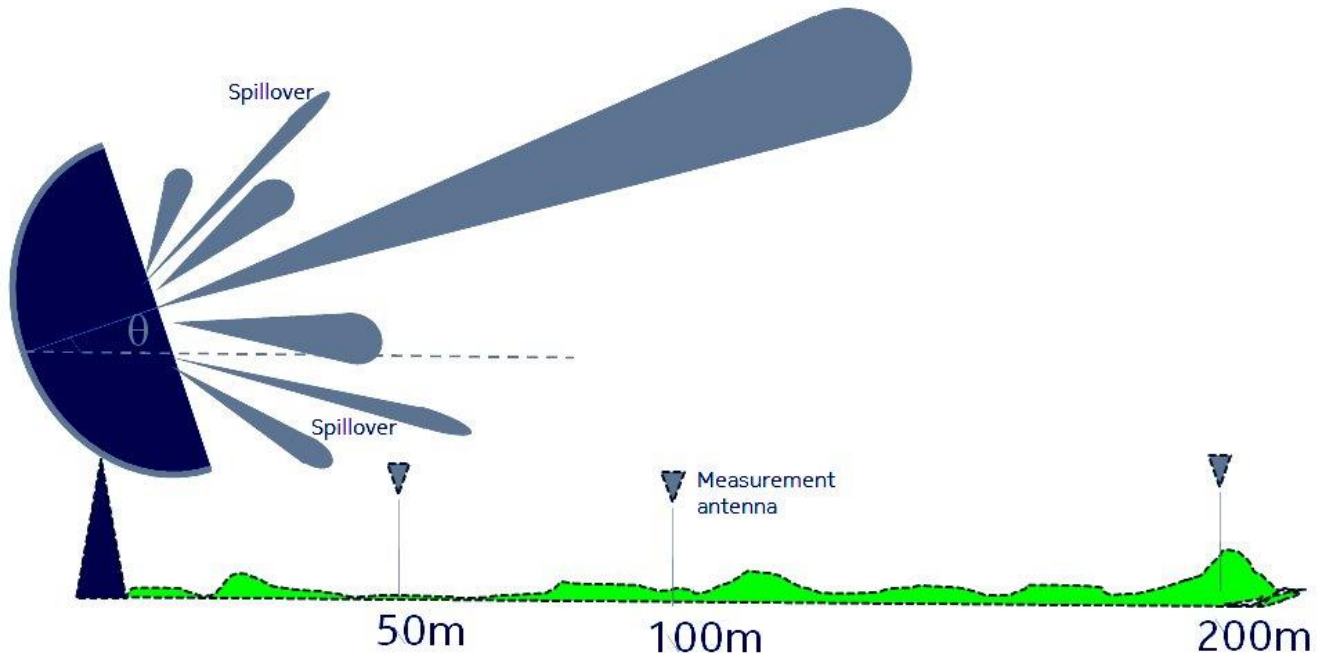


Figure 2: Spillover Radiation Measurement with Antenna Above Ground Level

### 2.1.2 Measurements

At each site an initial pre-sweep was performed to assess the actual antenna generating emissions and to assess the possibility of reflective sources nearby. All initial measurements were made with a sweep of the 27.5 to 30 GHz frequency range. Upon identifying the radiating source/s and frequency range of interest, the following measurements were performed over the appropriate frequency range.

1. Measurements were performed at varying distances (between 30m and 400m) depending on accessibility and clear line of sight (LOS) between measurement and FSS earth station antenna. A Laser range finder was used to verify distance. ( $\pm 0.9\text{m}$  accuracy).
2. Measurements were performed at varying radial angles around the target FSS earth station antenna depending on accessibility and LOS between measurement and FSS earth station antenna.
3. Measurements were performed at a vertical height of 2m, 4.5m, 5m and 6m above the ground plane.
4. Measurements were performed at each instance above after maximizing signals with azimuth and up/down tilt angle adjustments.
5. Measurements were performed for both the vertical and horizontal polarization of the measurement antenna.

### 2.1.3 Test Measurement Setup

The measurement setup depicted below was devised to provide reliable measurements in the band of interest. It was known that the individual sites would have numerous transmit emissions in various bands and it was important that these signals have no effect on our specific measurements of interest.

The measurement setup therefore consisted of a narrow beamwidth and high gain horn antenna followed by hard preselection prior to the Low Noise Amplifier (LNA). The hard preselection was provided by a coaxial 27.5-30 GHz band pass filter developed for this measurement. This was necessary to eliminate all signals outside the band of interest from being applied to the LNA. The LNA had an input attenuator to stabilize VSWR and an output attenuator to preclude possible damage from an unterminated output. The entire preselector-LNA- cable signal path verified as a combined unit prior to testing.

The antenna-filter-LNA assembly was mounted on an azimuth-tilt adjustment mechanism to allow for maximizing signal level. The combined antenna mechanism was mounted on the extendable mast of a measurement vehicle. The measurement instrument, a high quality 40 GHz low noise floor measurement receiver/ spectrum analyzer was mounted inside the climate controlled vehicle. A very low loss solid center conductor flexible cable connected the analyzer with the antenna system on the top of the mast.

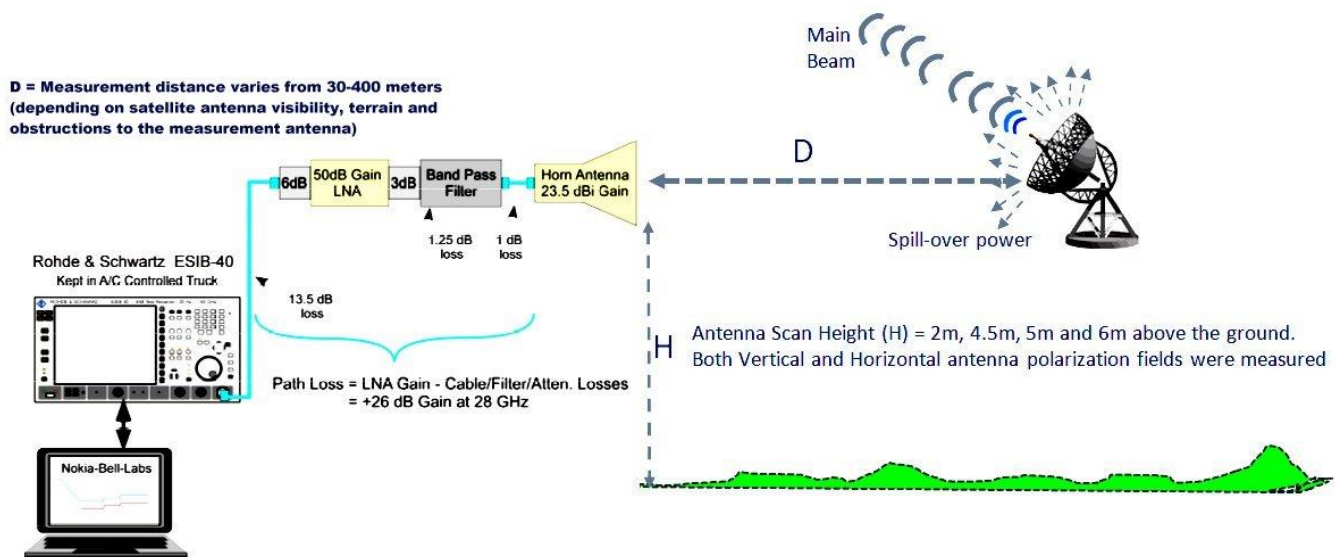


Figure 3: Test Measurement Setup

## 2.1.4 Computational Basis for Power Flux Density at the 5G Systems Receive Antenna

*Using Friis Transmission Formula - from the Friis Transmission Formula*

$$P_r = P_d \bullet A_{er} \quad (1)$$

where:

- $P_r$  = Measured power at 50 $\Omega$  analyzer input (W/MHz)
- $P_d$  = Power flux density (W/m<sup>2</sup>/MHz)
- $A_{er}$  = Antenna effective aperture (m<sup>2</sup>)

and

$$A_{er} = G\lambda^2/4\pi \quad (2)$$

$$G = (4\pi \bullet A_{er})/\lambda^2 \quad (3)$$

in dBm form

$$P_{d-dBm} = P_{measdBm} - G_{Preamp} - G_{dBi} - 10\log_{10}(\lambda^2/4\pi) \quad (4)$$

where:

- $G$  = Numerical Isotropic Antenna Gain
- $\lambda$  = Wavelength of frequency (m)
- $P_{d-dBm}$  = Power flux density (dBm/m<sup>2</sup>/MHz)
- $P_{measdBm}$  = Measured power at 50 $\Omega$  analyzer input (dBm/MHz)
- $G_{Preamp}$  = preamp gain – (cable+filter+attenuator loss) (dB)
- $G_{dBi}$  = Antenna Gain (dBi)



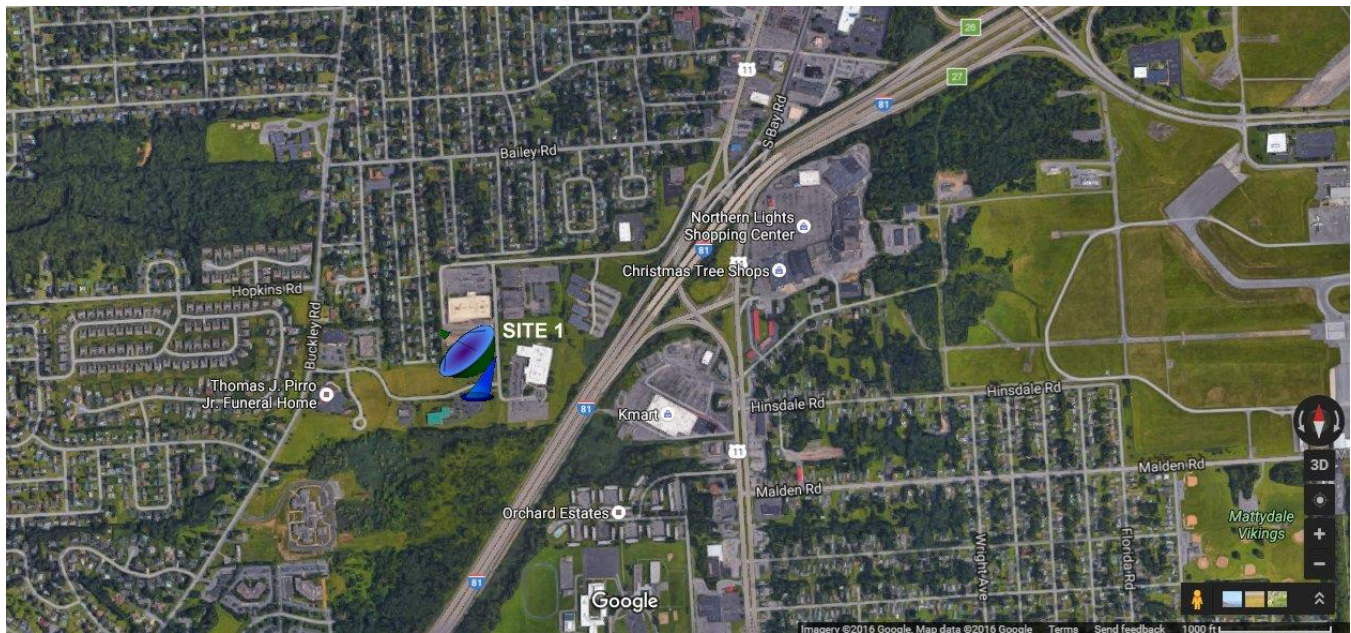
### 3. Measurement Sites

Sites have been identified by numbers only to maintain anonymity.

#### 3.1 SITE 1 – A Geosynchronous FSS Station.

##### 3.1.1 Site Aerial View

- There are offices and homes within 100~200m of the site.
- The site is approximately 2 km west of an International Airport.



### 3.1.2 FSS Earth Station Dish Antenna Details

- Three active FSS earth station antennas.
  - Active in the frequency range of 28.35 to 28.6 GHz and 29.25 GHz to 30.0 GHz.
- Two 8.1m and a single 5.6m diameter dishes. The Emissions Designator is 22M5G7W.
  - All three dish antenna are center feed sub-reflector style, circularly polarized.
    - *Expected measured V & H values are 3dB down from LHP and RHP.*
  - The Antennas line of focal point elevation with respect to Horizontal plane is 30.2° E – 7.4° W.
  - The Antennas Azimuth limits are 223.6E - 254.5W degrees.
  - Maximum EIRP towards Horizon = -15.6 dBW/4kHz.
- The two 8.1m diameter dish antennas are manufactured by Andrew Corporation ES-81-KA-1.
  - Max Gains = 62.4 dBi @ 19.95 GHz and 65.6 dBi @ 29.75 GHz.
  - Maximum total input power at antenna flange = 250.6 Watts.
  - Maximum aggregate output EIRP for all carriers = 89.3 dBW.
- The 5.6m diameter dish antenna is an manufactured by Andrew Corporation ES-56-KA-1.
  - Max Gains = 59.7 dBi @ 19.95 GHz and 62.6 dBi @ 29.75 GHz.
  - Maximum total input power at antenna flange = 250.6 Watts.
  - Maximum aggregate output EIRP for all carriers = 86.3 dBW.

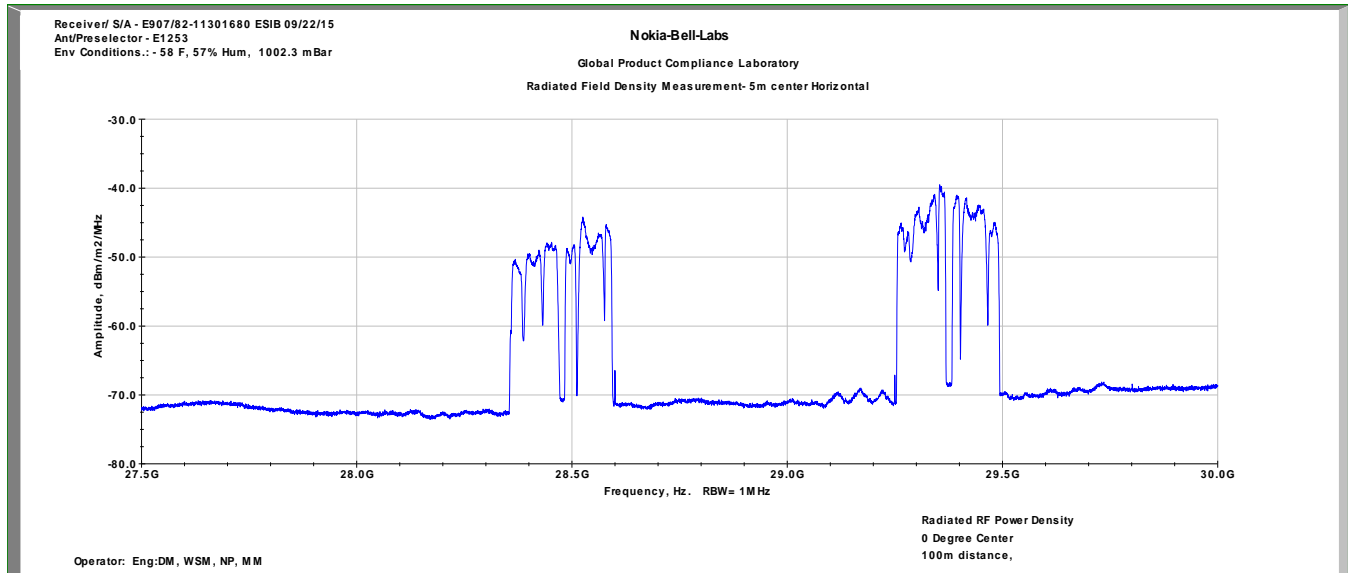
### 3.1.3 Site Measurement Details

- Tested: June 12<sup>th</sup>, 2016 through June 18<sup>th</sup>, 2016.
- Relatively Flat Terrain (no elevation change) and Clear Line of Sight for 100m, 200m & 280m in front of antenna.
  - Measurements were made in ideal weather conditions (cloudless clear skies).
- Measurements performed at 0°, 22.5° CW, 120° CCW and 180° with respect to middle FSS earth station antenna.
- All measurements were made at 2m, 4.5m, 5m and 6m antenna heights.
- The 0° measurements were made at distances of 100m, 200m, 280m and 400m.
  - Even Terrain (no elevation change) and Clear Line of Sight for 100m, 200m & 280m.
- The 22.5 ° CW measurements were made at 100m and 200m.
- The 120° CCW measurements were made 50m, 100m and 200m.
- The 180° measurements were made at 100m and 200m.

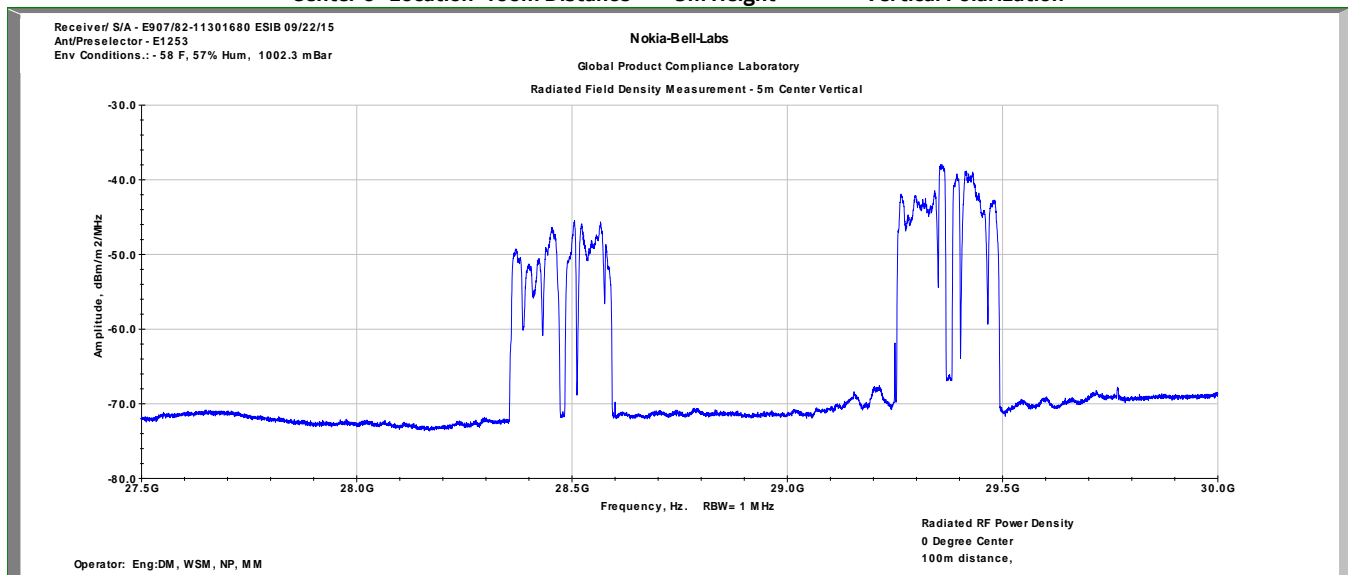


### 3.1.4 Measured Data Plots

#### 3.1.4.1 Sample EMI Receiver Scans

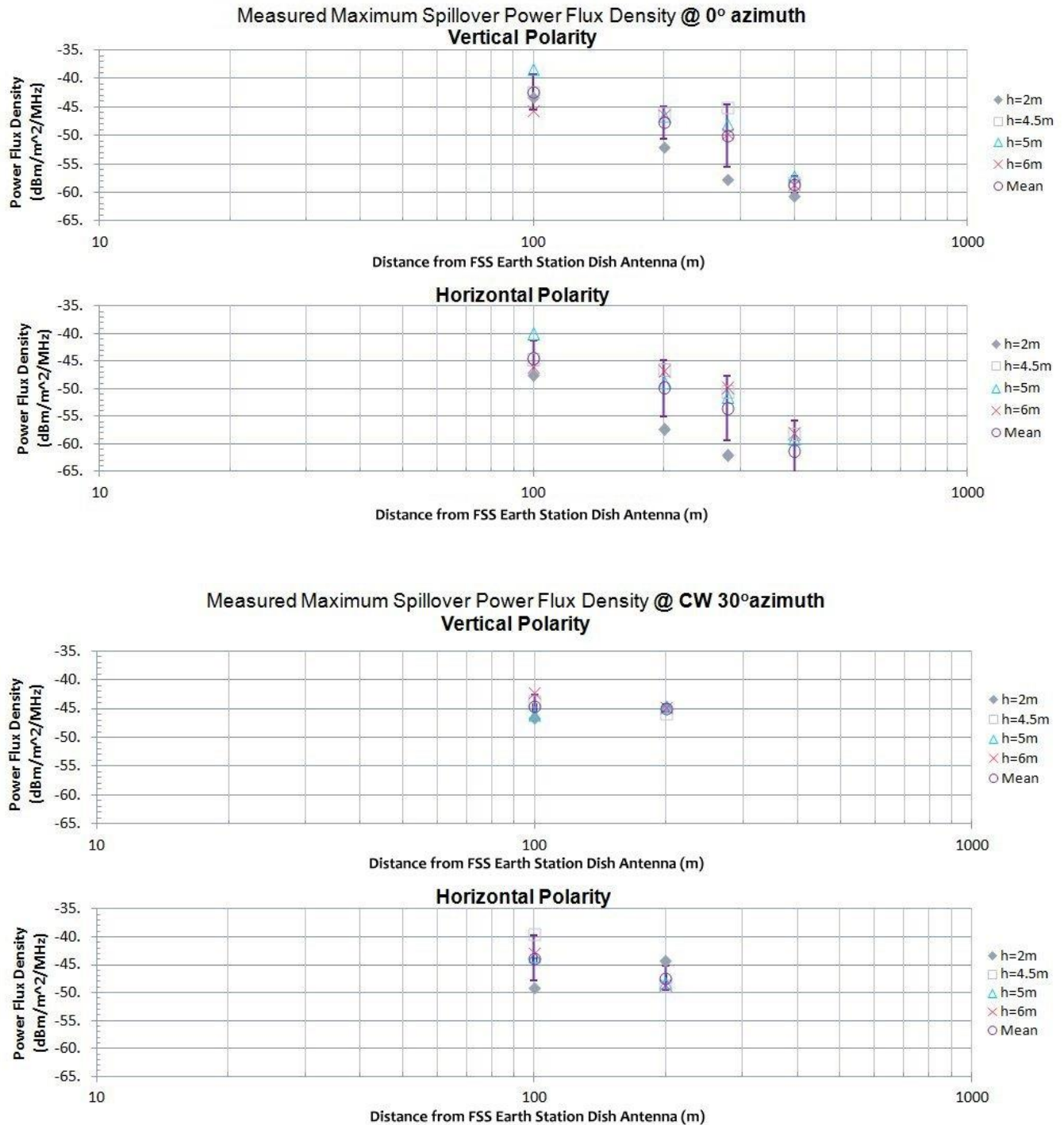


Center 0° Location 100m Distance 5m Height Vertical Polarization

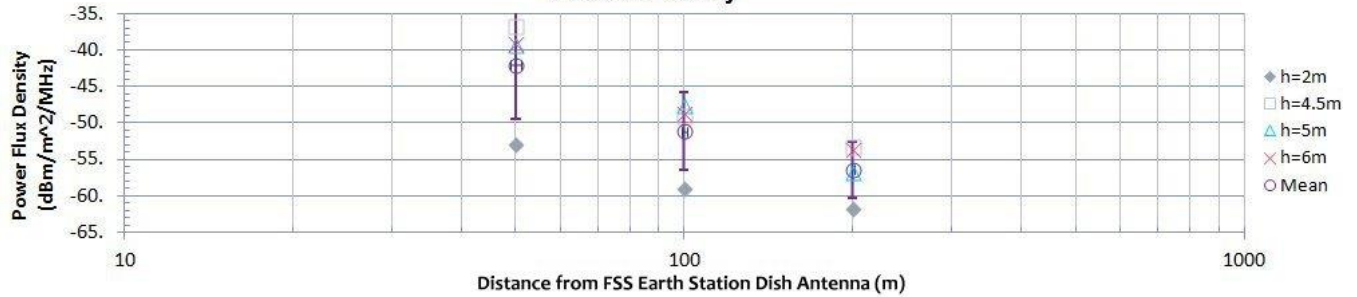




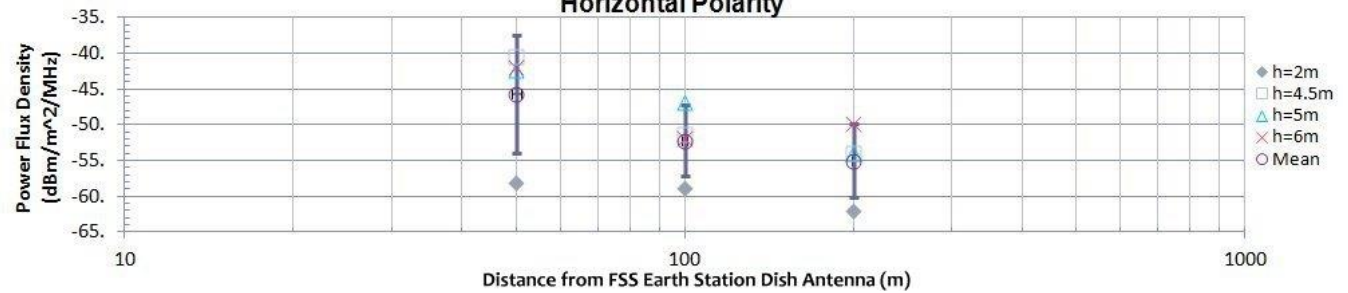
### 3.1.4.2 Effect of Distance and Receive Antenna Height on Measured Power Flux Density



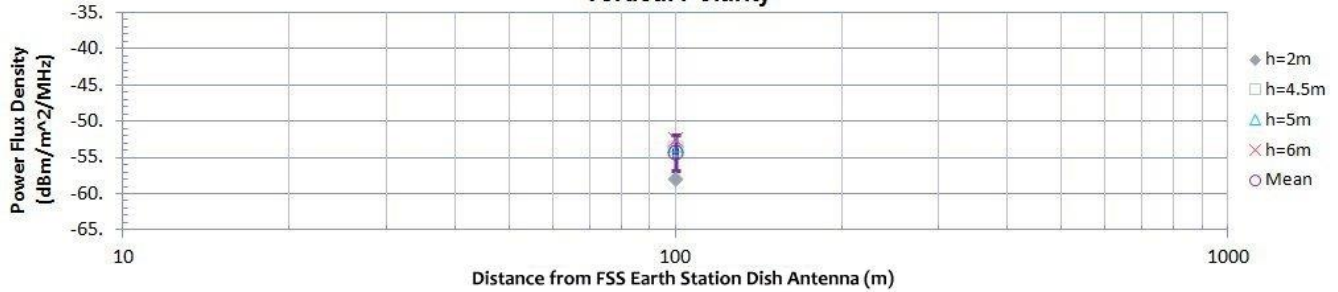
Measured Maximum Spillover Power Flux Density @ CCW 90° azimuth  
Vertical Polarity



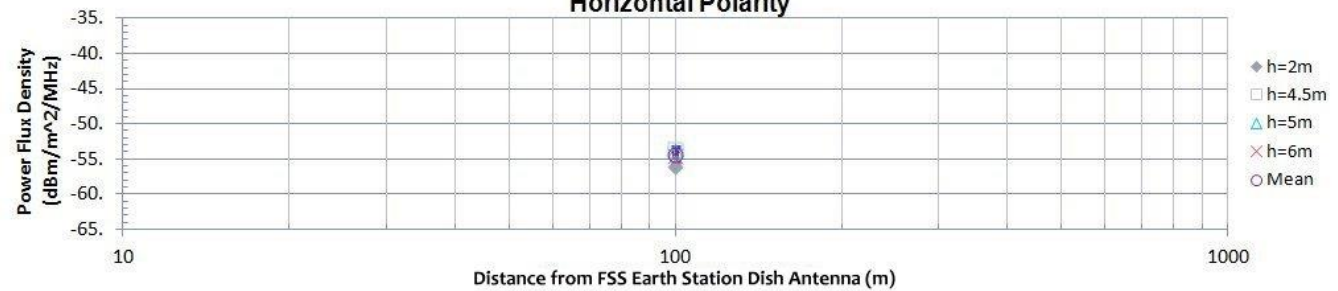
Horizontal Polarity



Measured Maximum Spillover Power Flux Density @ 180° azimuth  
Vertical Polarity



Horizontal Polarity



### 3.1.5 Site Photos

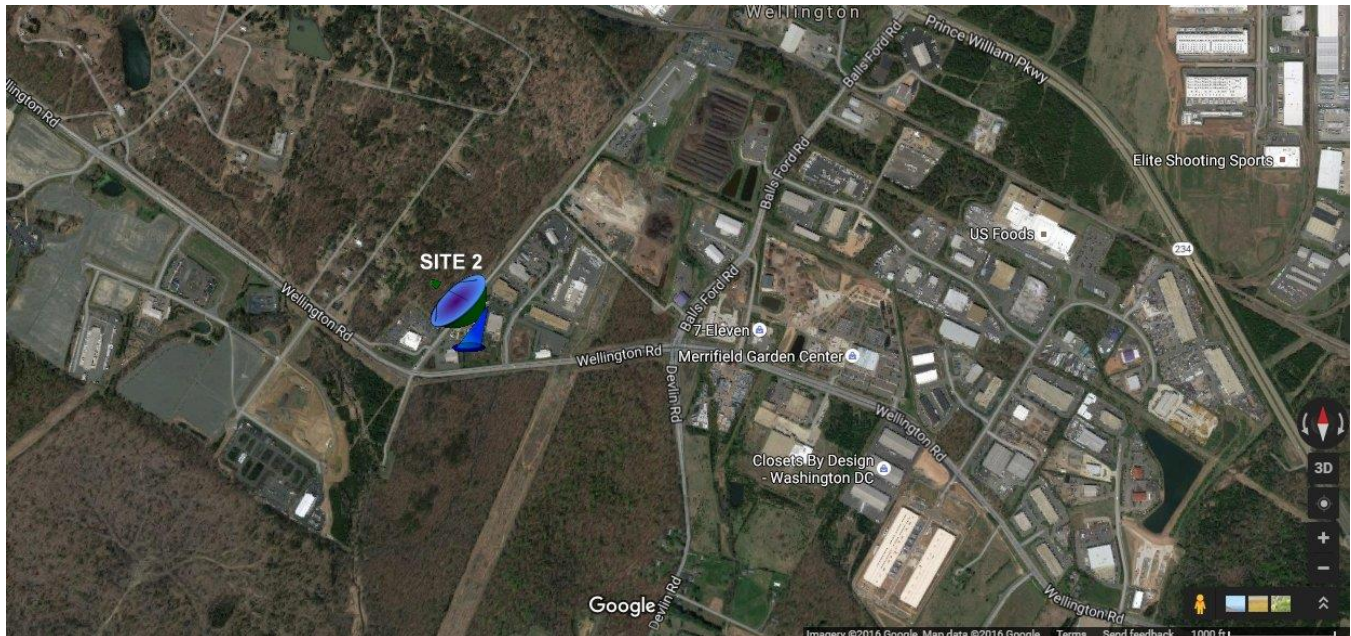




## 3.2 SITE 2 - A Near Earth Orbit site co-located with a larger FSS site.

### 3.2.1 Site Aerial View

- 30 Miles from major metropolitan area.
- Industries and offices nearby.
- More than 900 meters to the nearest homes.
- 7 sets of dual antenna Near Earth Orbit systems set up for training and operation.
- 18+ other FSS SES dish systems present.



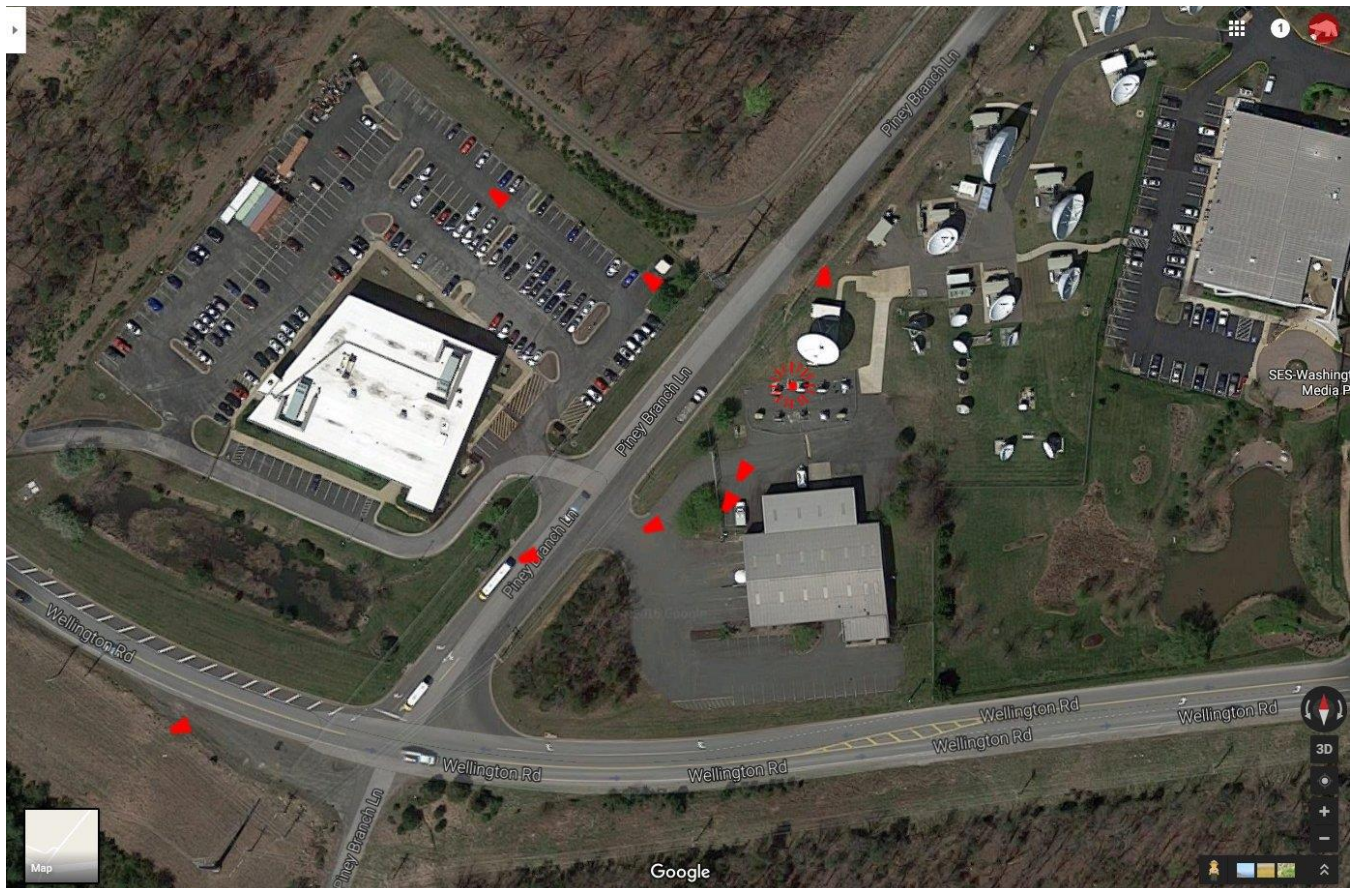


### 3.2.2 FSS Earth Station Dish Antenna Details

- Seven FSS earth station antenna systems were active in the 28 GHz band.
  - The 28 GHz service was operated for Near Earth Orbit (NEO) Spacecraft.
  - The antenna are circularly polarized.
  - Expected V & H values are ~3dB down from LHP and RHP.
- Seven dish antenna pairs operational at 27.5 GHz to 27.9 GHz actively tracking NEO spacecraft.
  - No other signals were present from 27 GHz -27.5 GHz or from 28 GHz -30 GHz.
    - The 1.8m diameter antennas were operating at 5W with overcast sky. Maximum feed power level is 40W.
    - The 2.4m diameter antennas listed maximum feed power = 35.9W. Max Gain = 55.2 dBi @ 28.3615 GHz
    - The 1.2m diameter antennas listed maximum feed power = 20W. Max Gain = 48.0 dBi @ 28.3 GHz
    - The minimum observed antenna focal point elevation with respect to the Horizontal plane was ~5deg.
    - The O3b dish antenna operate in pairs. Dish #1 transmits to overhead s/c while dish #2 waits for the next s/c.
    - Emissions Designators are 1M00G7D and 216MG7D.
    - There were more than 17 other active antennas at this site operating in different frequency bands.
- The 2.4m Diameter Antennas were Licensed 6/24/2015
  - The FCC authorized max EIRP level was 70.75 W/carrier (48.5 dBm/carrier)
    - Maximum EIRP toward Horizon is 32.1 dBm/MHz (-21.9 dBw/4kHz).
    - Antenna line of focal point elevation with respect to Horizontal plane is 7.6° E – 7.0° W.
- The 1.2m Diameter Antennas were Licensed 9/30/2015
  - The FCC authorized max EIRP level was 60.6 W/carrier (47.8 dBm/carrier)
    - Maximum EIRP toward Horizon is 14.2 dBm/MHz (-39.8 dBw/4kHz (units not clear on license-assumed)
    - Antenna line of focal point elevation with respect to Horizontal plane is 10 deg

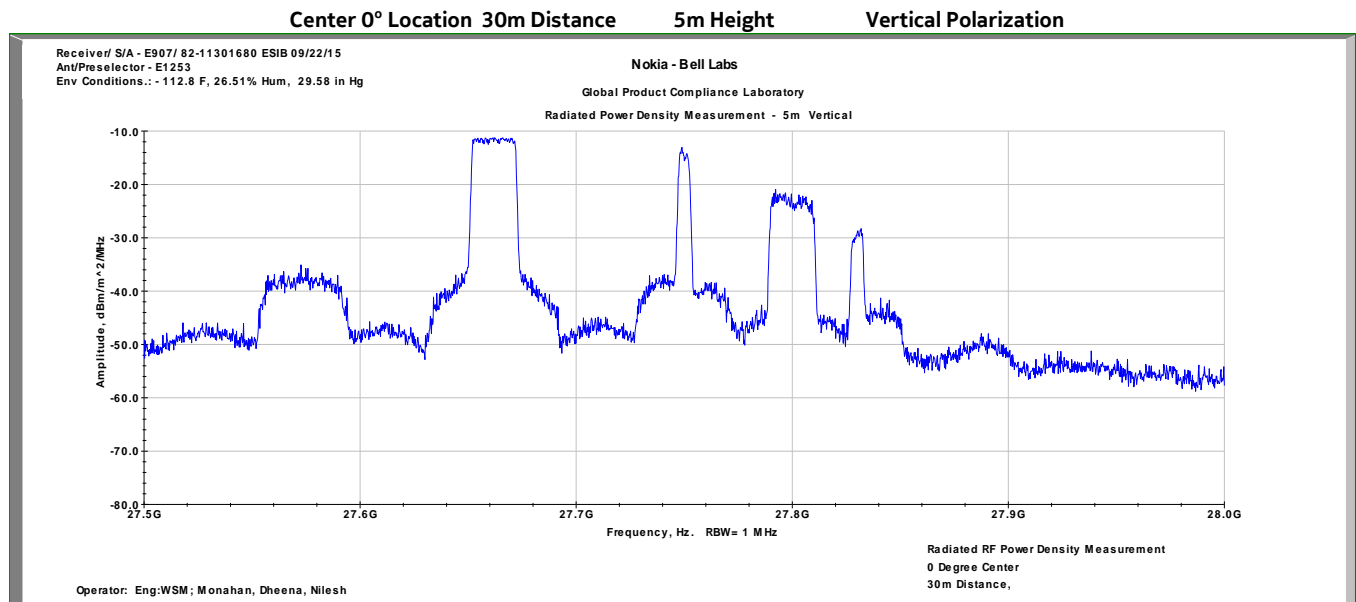
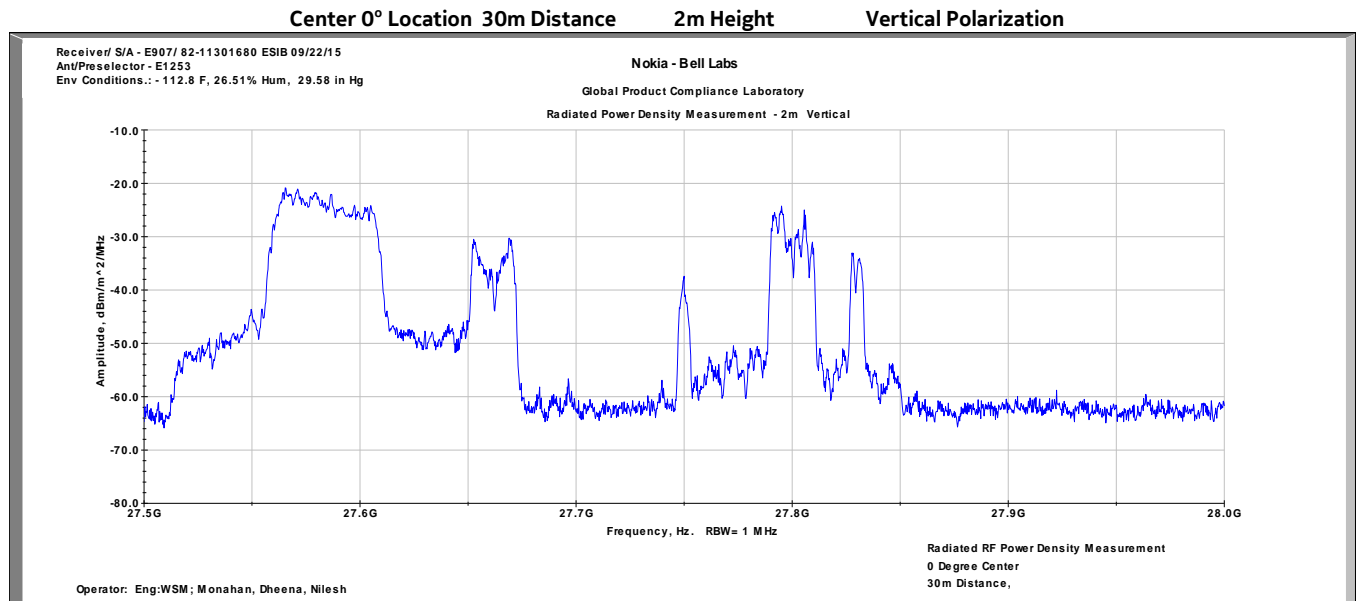
### 3.2.3 Site Measurement Details

- Tested: June 20<sup>th</sup>, 2016 through June 24<sup>th</sup>, 2016.
- Measurements were made at 0°, 90° CW and 180° with respect to middle FSS earth station antenna nominal.
  - All measurements were made at 2m, 4.5m, 5m and 6m measurement antenna heights.
  - The 0° measurements were made with ideal clear sky weather. All other measurements had overcast sky.
- The 0° measurements were made at distances of 30m, 40m, 50m, 100m and 200m.
  - These measurements had flat down-sloping terrain away from the site.
  - Elevation loss was > 5m at 200m distance.
- The 90° left measurements were made at 50m (on road), 100m and 140m.
  - The 100m and 140m measurements had even terrains with a 0.8m high roadway berm outside dish site.
- The 180° measurements were made at 30m with a 2m elevation rise.

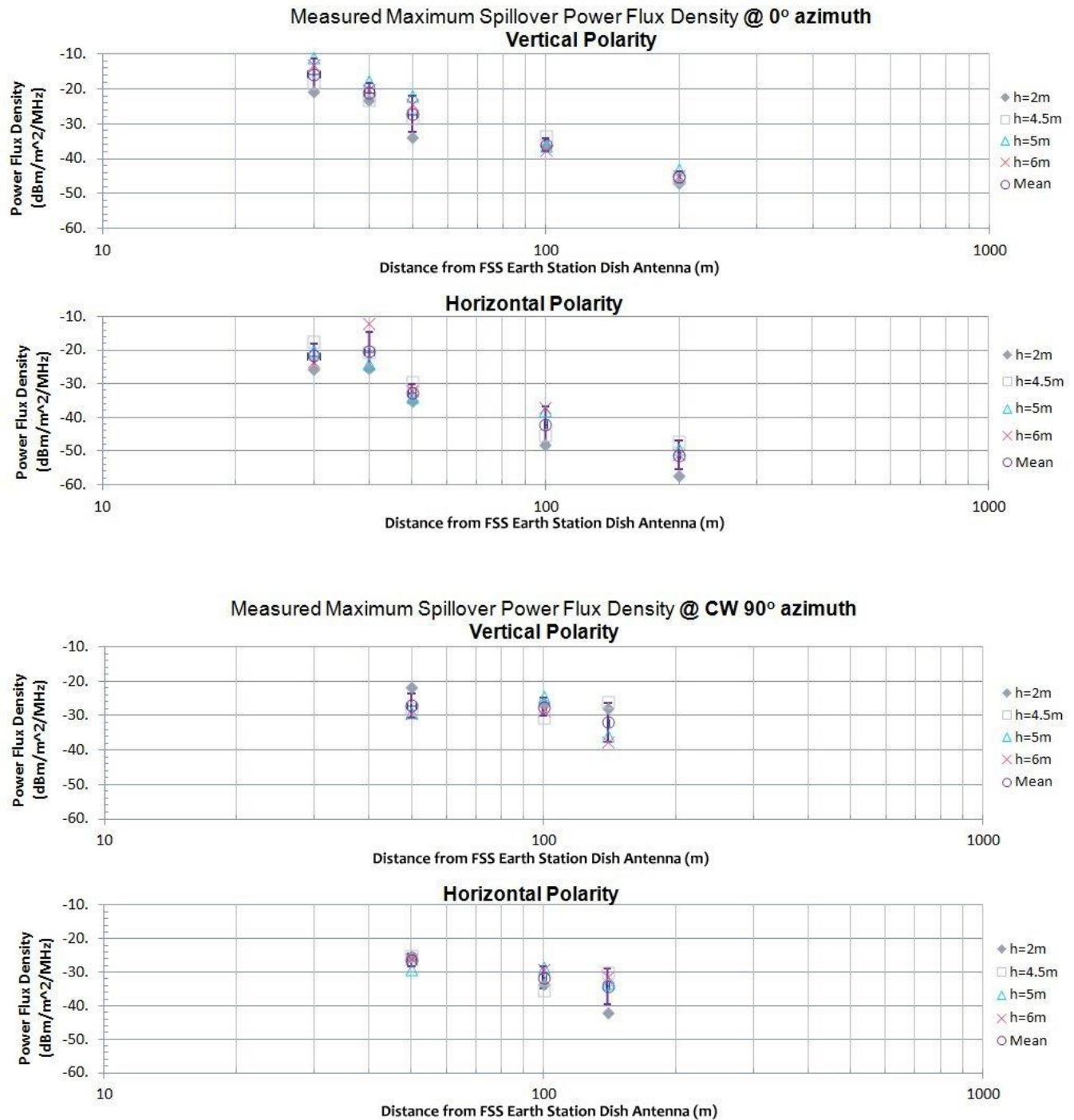


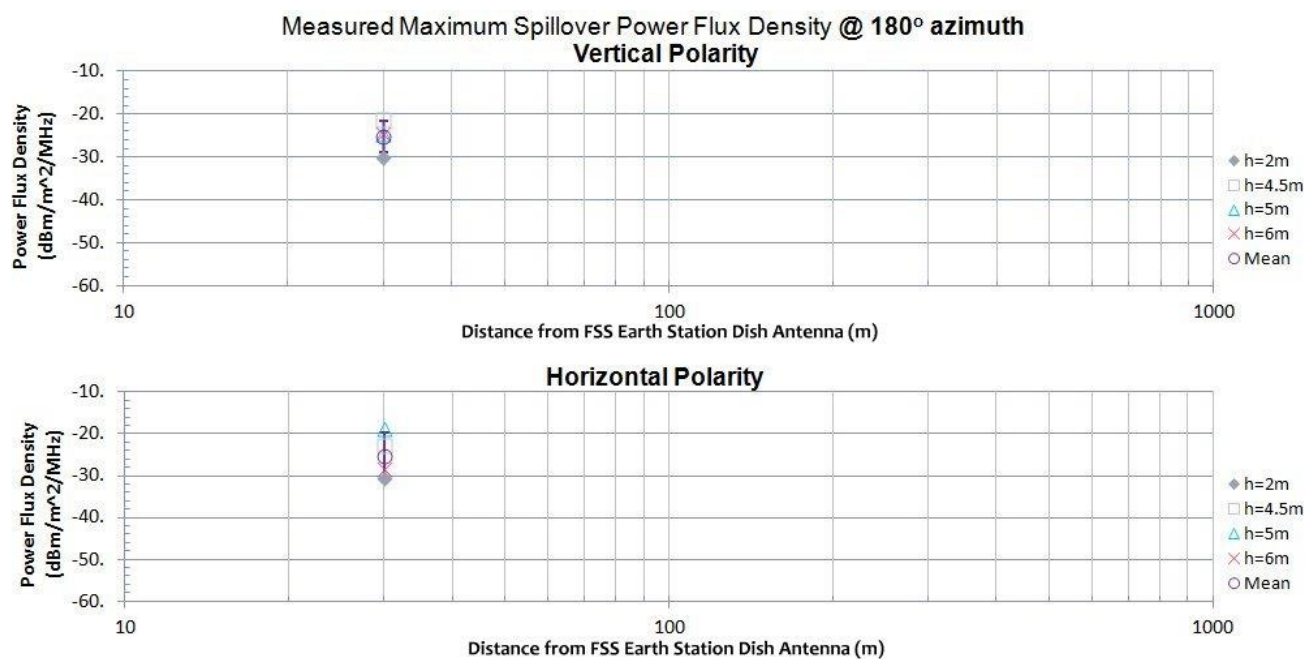
### 3.2.4 Measured Data Plots

#### 3.2.4.1 Sample EMI Receiver Scans



### 3.2.4.2 Effect of Distance and Receive Antenna Height on Measured Power Flux Density







### 3.2.5 Site Photos

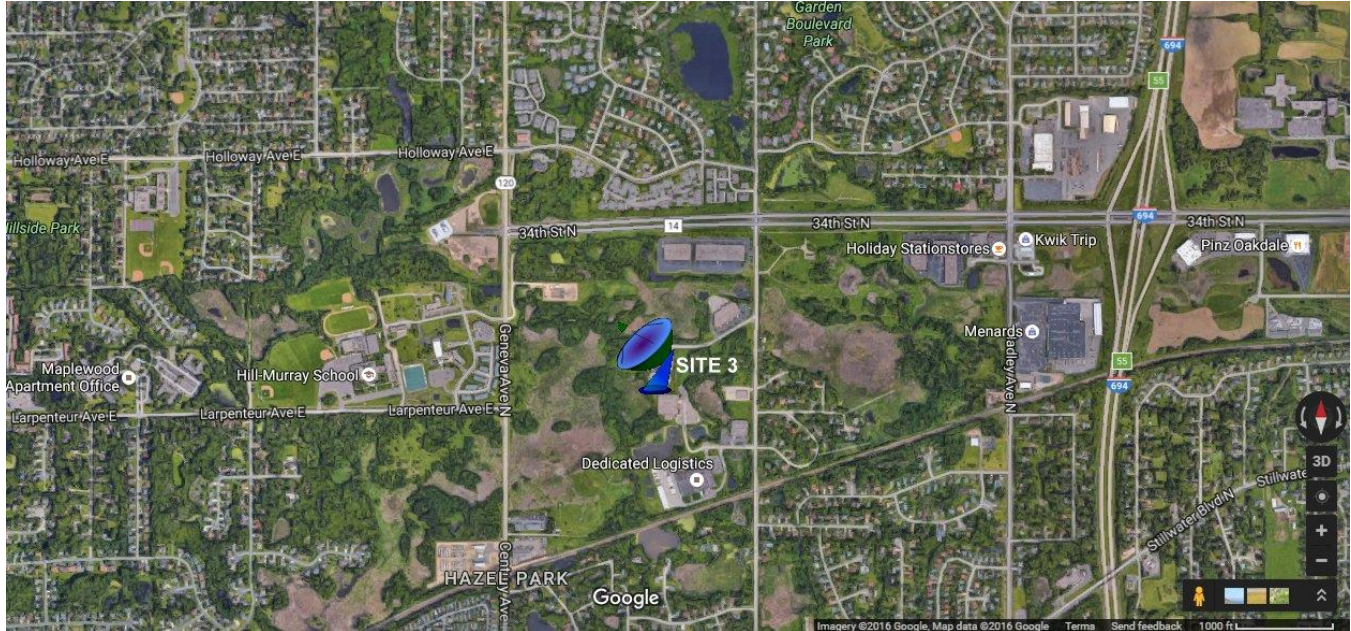




### 3.3 SITE 3 – A Geosynchronous FSS Station.

#### 3.3.1 Site Aerial View

- 50m to nearest business. Three additional businesses 230m away.
- Nearest homes are 330m. Most are more than 500m away.
- 2 dishes operating at 28 GHz, minimum of 4 more dishes at other frequencies.



### 3.3.2 FSS Earth Station Dish Antenna Details

- Two active FSS earth station antennas, KA1 and KA2, licensed for the same signals.
  - Max Gains(s): 70.0 dBi @ 30.0 GHz , 65.4 dBi @ 20.2 GHz
  - Maximum total input power at the antenna flange = 447.0 Watts
  - Maximum aggregate output EIRP for all carriers = 96.5 dBW
- Center feed sub-reflector style, circularly polarized.
  - Expected measured V & H values are 3dB down from LHP and RHP.
- Active transmissions from 28.35-29.5 GHz and 29.25-30.00 GHz.
- The 13.2m Diameter Vertex RSI Antennas were Licensed 12/12/2014.
  - The FCC authorized max EIRP level was 85.10 W/carrier (45.60 dBm/carrier)
    - Maximum EIRP toward Horizon is 29.9 dBW/4kHz
    - Antenna line of focal point elevation with respect to Horizontal plane is 36.6° E – 31.7° W
    - Antenna Azimuth limits of 161.9° E – 215.8° W



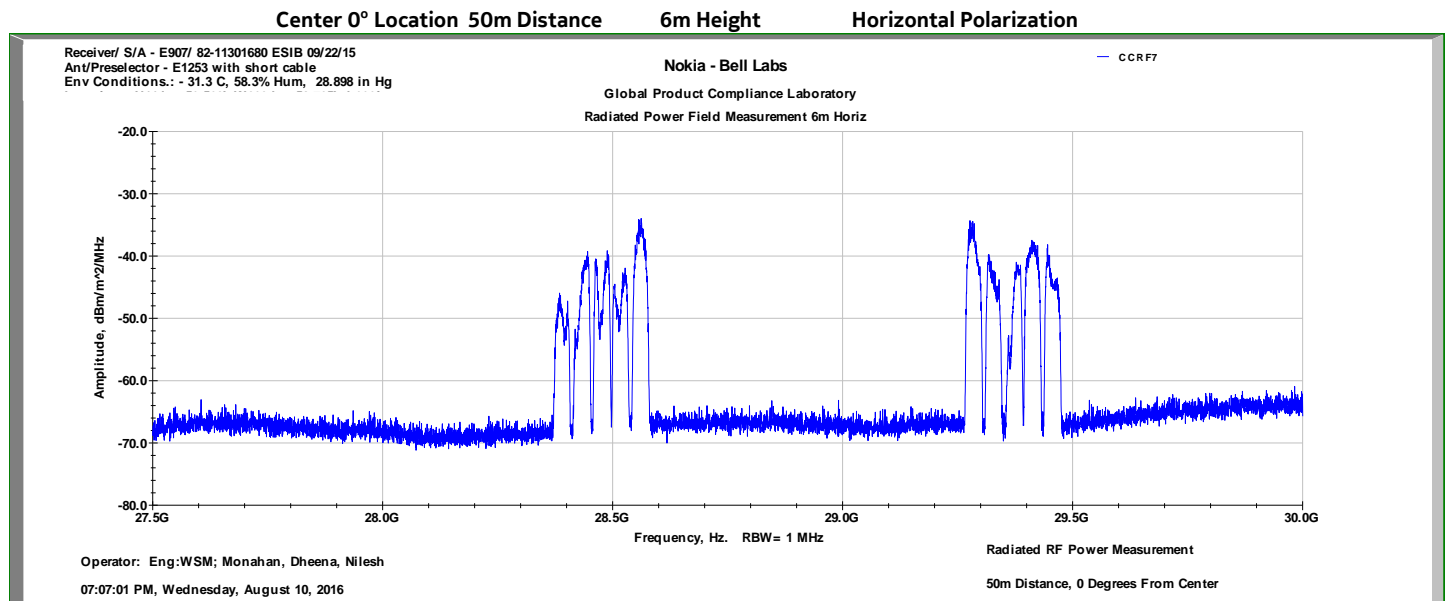
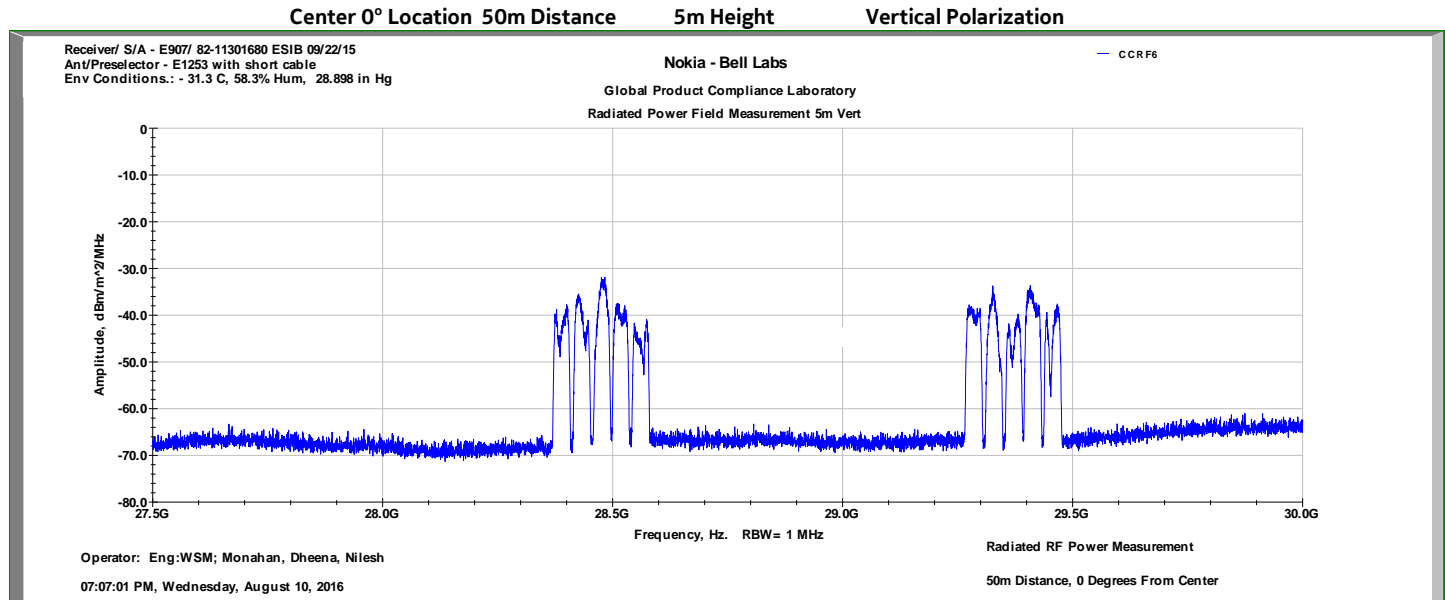
### 3.3.3 Site Measurement Details

- Tested: August 8<sup>th</sup>, 2016 through August 11<sup>th</sup>, 2016.
- Measurements were made in mostly cloudy skies.
- Measurements performed at 0°, 90° CCW and 210° Rear with respect to midpoint of the two FSS earth station antennas.
  - Flat terrain - No elevation change for any measurement.
- The 0° measurements were made at 50m only due to limited accessibility.
- The 90° CCW measurements were made at 85m and 125m.
- The 210° measurements were made at 50m and 80m
- All measurements were made at 2m, 4.5m, 5m and 6m measurement antenna heights.

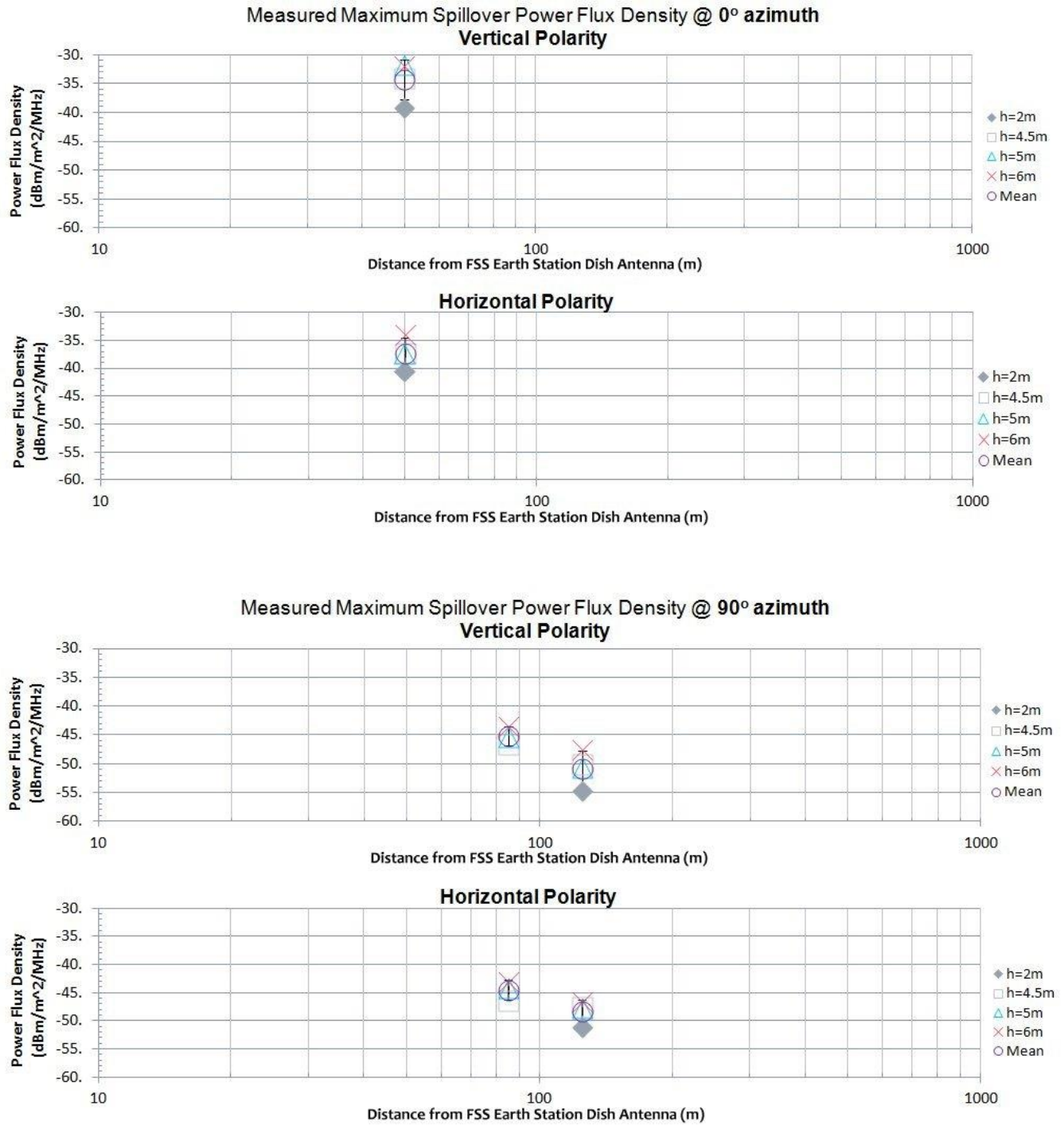


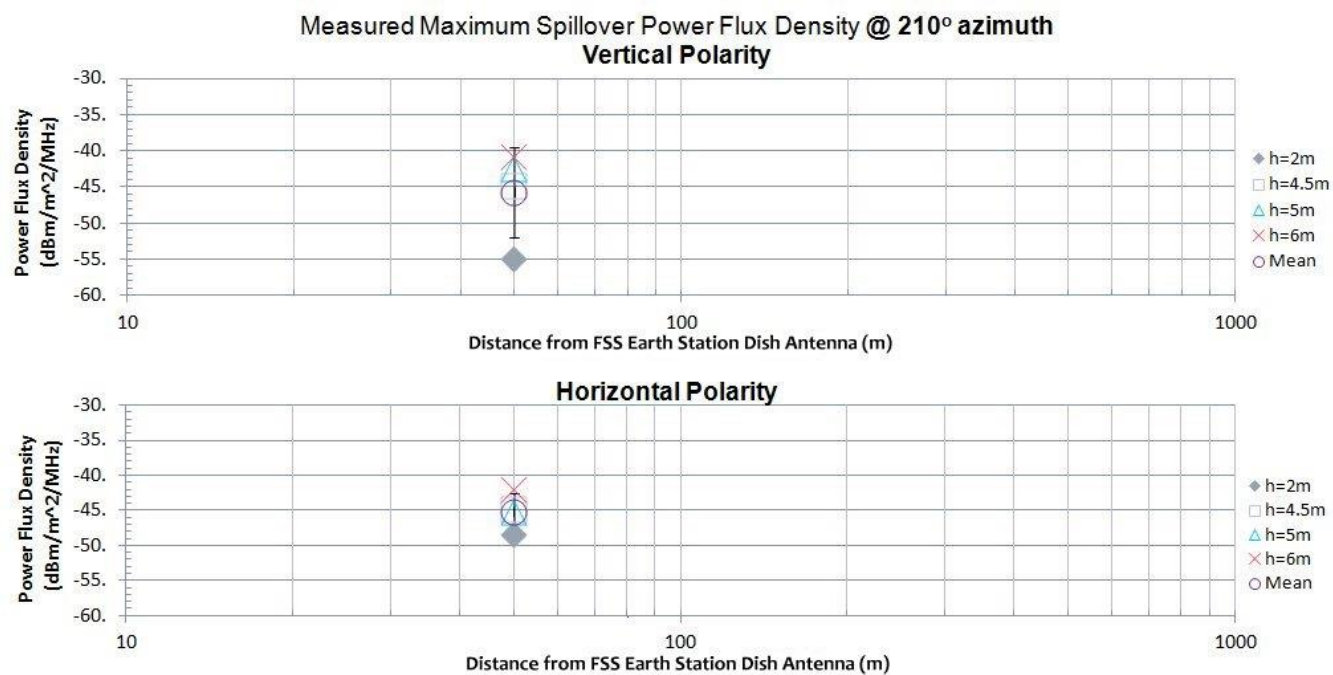
### 3.3.4 Measured Data Plots

#### 3.3.4.1 Sample EMI Receiver Scans



### 3.3.4.2 Effect of Distance and Receive Antenna Height on Measured Power Flux Density







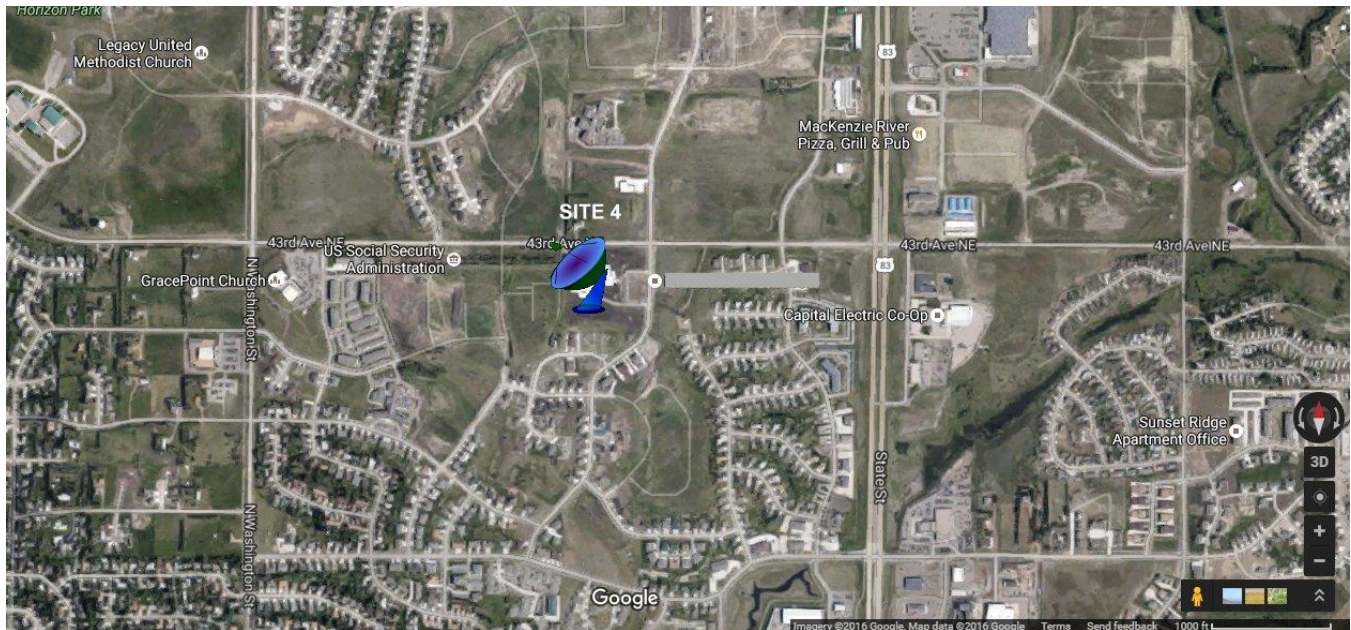
### 3.3.5 Site Photos



### 3.4 SITE 4 – A Geosynchronous FSS Station.

#### 3.4.1 Site Aerial View

- About 3 miles to town center.
- IT company located on site. Industry and Offices on left and right sides (< 400m)
- More than 230 meters to nearest homes.
- 2 dishes operating at 28 GHz. Third dish on site awaiting spacecraft launch.
- 275m to Microwave Distribution System / Cellular Tower with 8 MDS antenna.



### 3.4.2 FSS Earth Station Dish Antenna Details

- There were two active FSS earth station antennas.
- Center feed sub-reflector style, circularly polarized.
  - Expected measured V & H values are 3dB down from LHP and RHP
- Licensed for transmissions from 27.85 GHz to 30 GHz
- Two active FSS earth station antennas, licensed for the same signals.
  - Max Gain(s): 62.0 dBi @ 20.2 GHz, 65.3 dBi @ 30.0 GHz
  - Maximum total input power at the antenna flange = 200.0 Watts
  - Maximum aggregate output EIRP for all carriers = 88.3 dBW
- Active transmissions from 29.5 -30.00 GHz.
- The 8.1m Diameter ASC Signal Antennas.
  - The FCC authorized max EIRP level/carrier is 88.3 dBW
    - Maximum EIRP toward Horizon is listed as -44.9 dBW/4kHz
    - Antenna line of focal point elevation with respect to Horizontal plane is 36.0° E – 36.0° W
    - Antenna Azimuth limits of 174.8° E – 174.8° W
    - Emission Designators range from 100KG7W to 250MG7D



### 3.4.3 Site Measurement Details

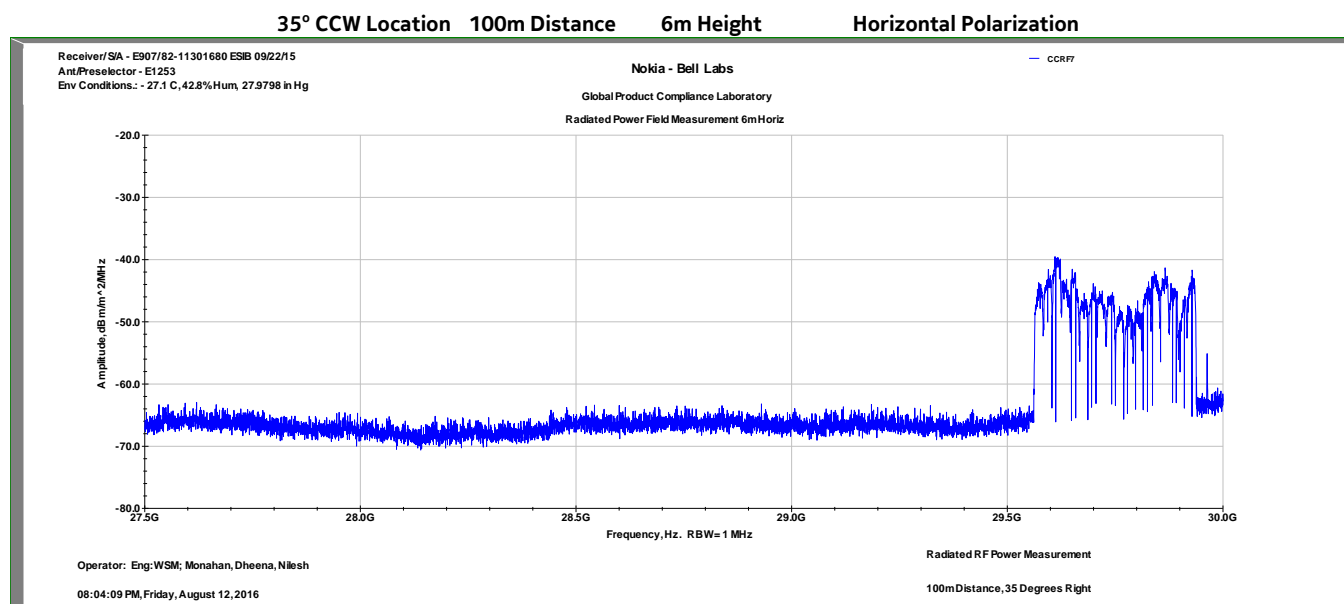
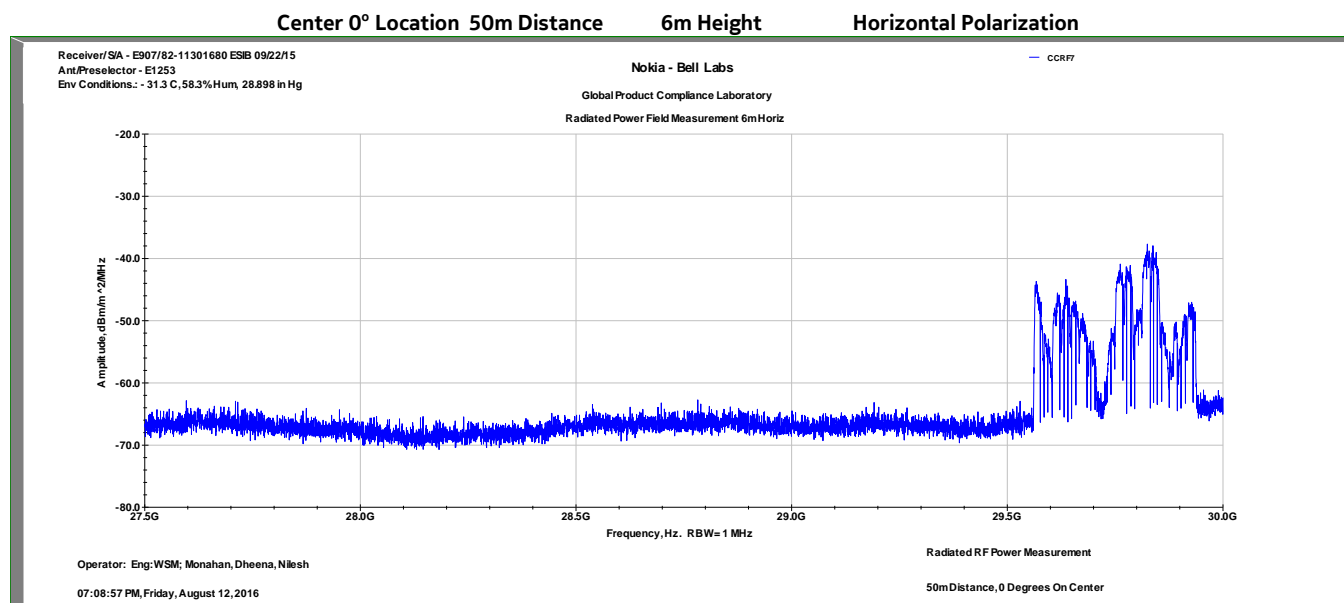
- Tested: August 12<sup>th</sup>, 2016.
- Two active FSS earth station antennas.
- Active transmissions from 29.5 GHz to 30 GHz
- The antenna are circularly polarized.
  - Expected measured V & H values are 3dB down from LHP and RHP.
- Measurements were made at 0° and 35° CCW with respect to midpoint of the two FSS earth station antennas.
- Both sets of measurements were made in clear skies.
- The 0° measurements were made at distances of 50m and 100m.
  - The measurement at 100m distance had an elevation gain of 4ft (1.22m).
- The 35° CCW measurements were made at 100m and 200m.
  - The measurement at 200m distance had an elevation loss of 12ft (3.66m) .
- All measurements were made at 2m, 4.5m, 5m and 6m measurement antenna heights.



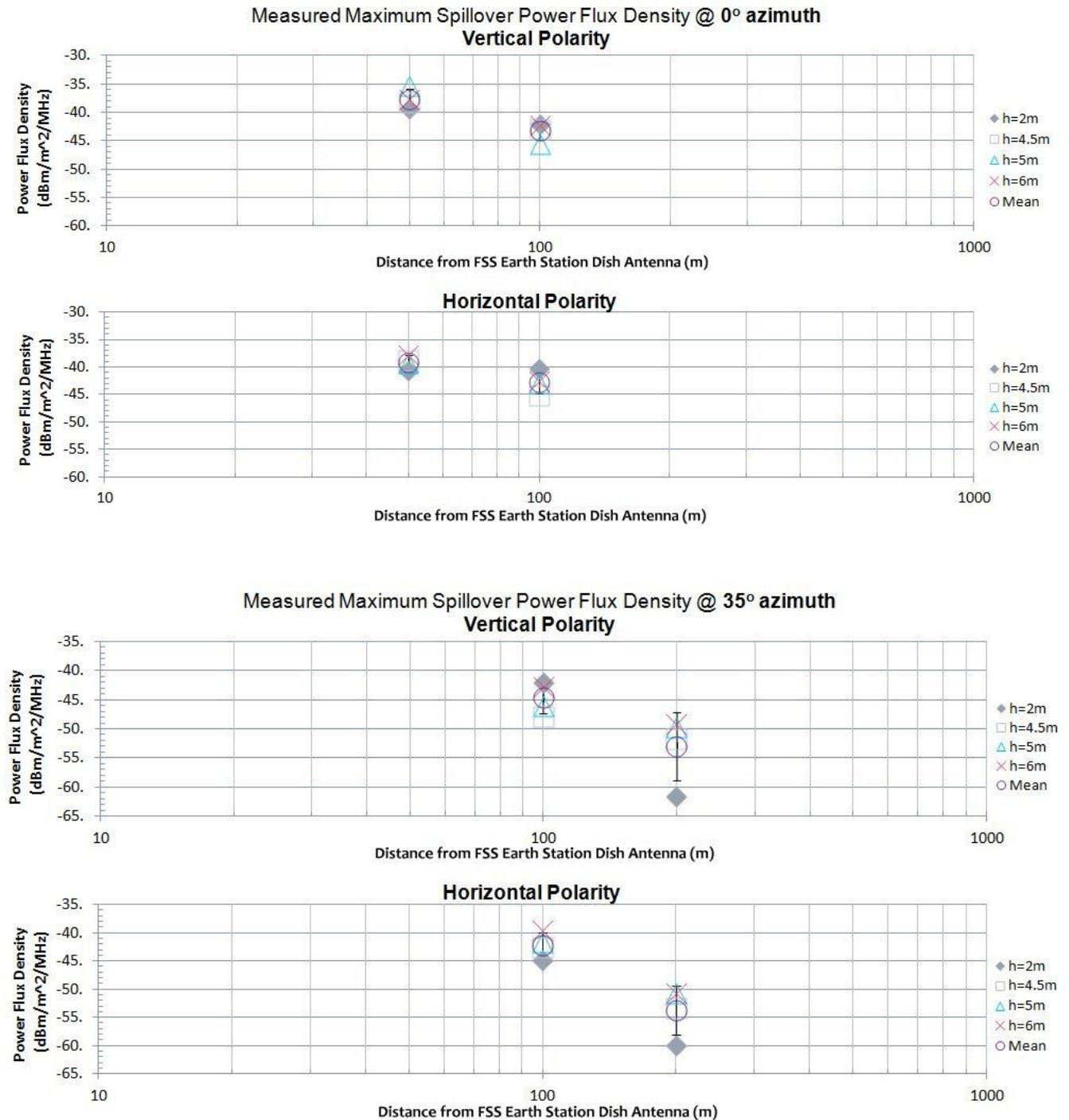


### 3.4.4 Measured Data

#### 3.4.4.1 Sample EMI Receiver Scans



#### 3.4.4.2 Effect of Distance and Receive Antenna Height on Measured Power Flux Density



### 3.4.5 Site Photos

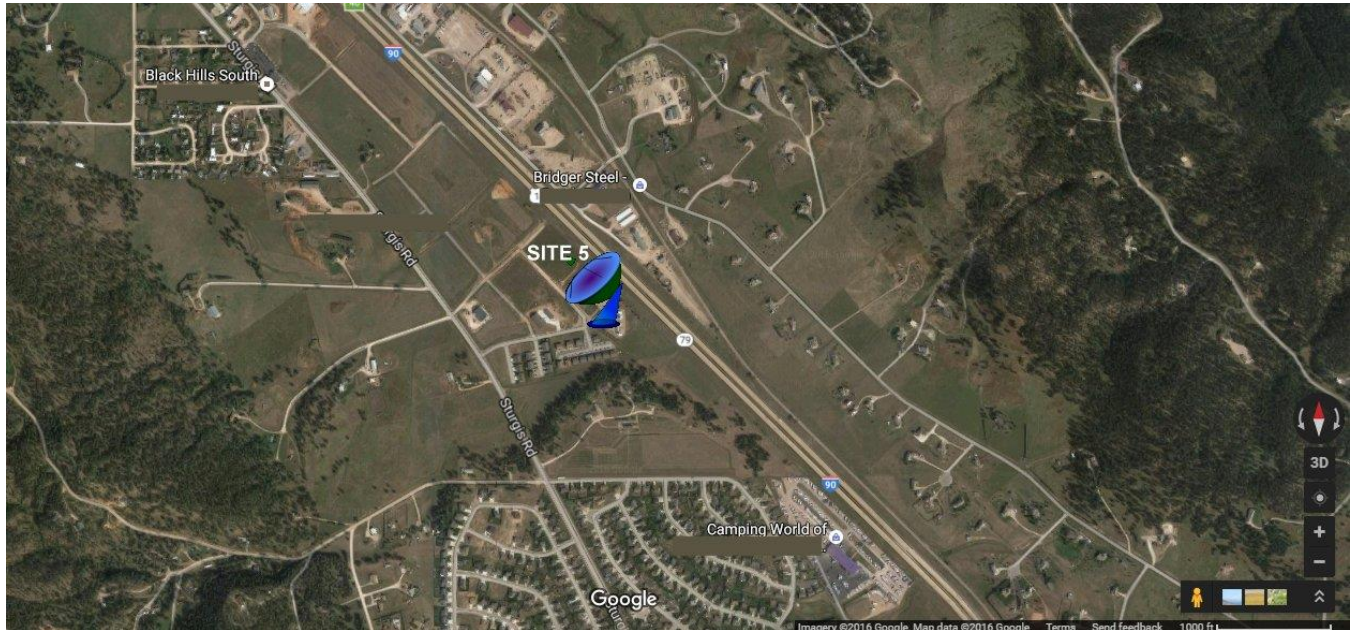




### 3.5 SITE 5 – A Geosynchronous FSS Station.

#### 3.5.1 Site Aerial View

- About 10 miles from an Air Force Base.
- 36 unit Apartment complex nearby starting at 70m with 12 homes beyond at 190m~300m.
- Nearest Business 180m to rear.
- 1 dish operating at 28 GHz, 3 other dishes on site operating at different frequencies.

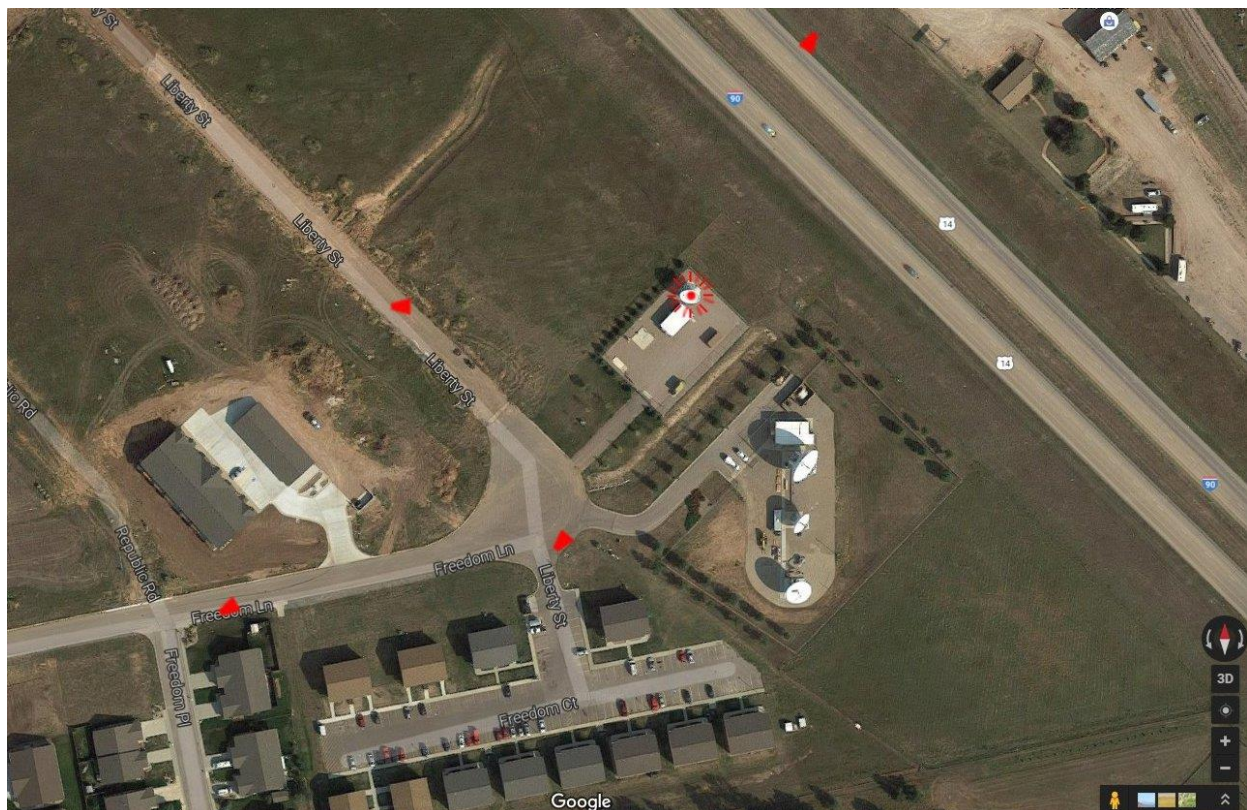


### 3.5.2 FSS Earth Station Dish Antenna Details

- Four dishes on site but only one was active at 28 GHz.
- Center feed sub-reflector style, circularly polarized.
  - Expected measured V & H values are 3dB down from LHP and RHP
  - Max Gains(s): 65.5 dBi @ 30.0 GHz.
    - 62.8 dBi @ 20.2 GHz, 61.9 dBi @ 18.3 GHz, 65.3 dBi @ 28.35 GHz, 65.4 dBi @ 29.10 GHz and 65.4 dBi @ 29.50 GHz
  - Maximum total input power at the antenna flange = 200.0 Watts
  - Maximum aggregate output EIRP for all carriers = 89.0 dBW
- Active transmissions from 28.1-29.1 GHz and 29.5-30.0 GHz.
- The 7.3m Diameter Antenna was licensed 10/21/2011.
  - Licensed to provide service to four possible spacecraft.
  - The FCC authorized max EIRP/carrier listed as 69.00 dBW
    - Maximum EIRP toward Horizon is -41.3 dBW/4kHz
    - Antenna line of focal point elevation with respect to Horizontal plane is 6.6° E – 7.3° W
    - Antenna Azimuth limits of 105.2E - 254.1W
    - Emissions Designators – 1K00N0N, 1M00G2D, 52M1G7D & 416MG7D

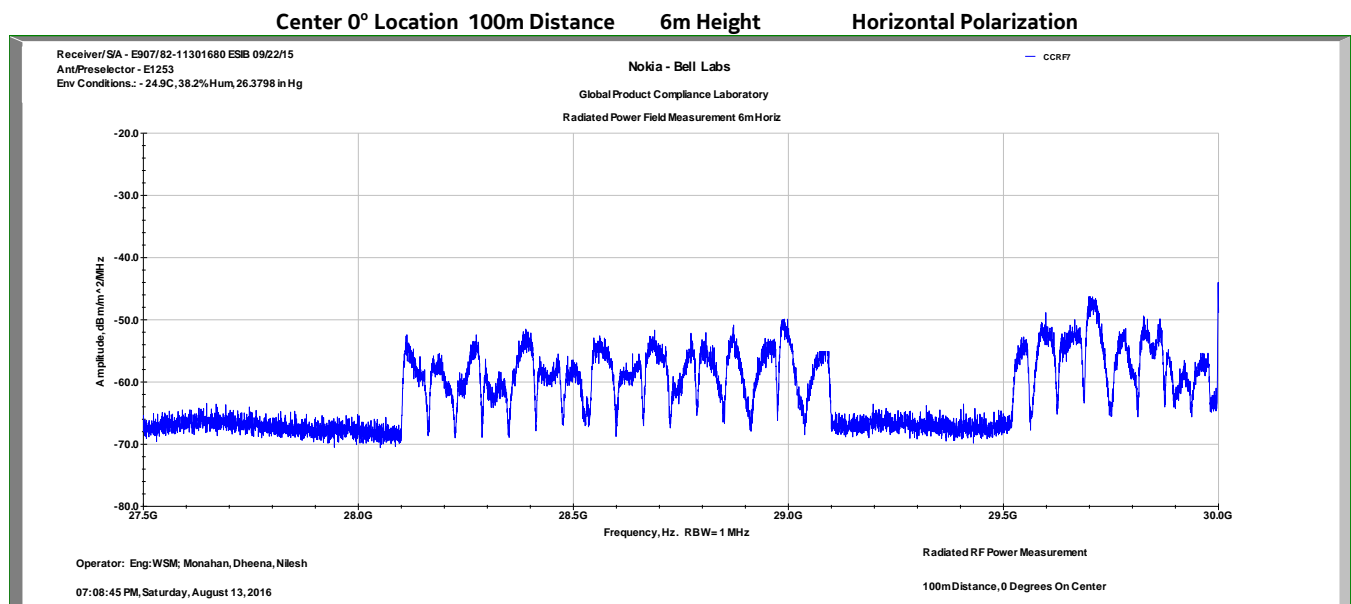
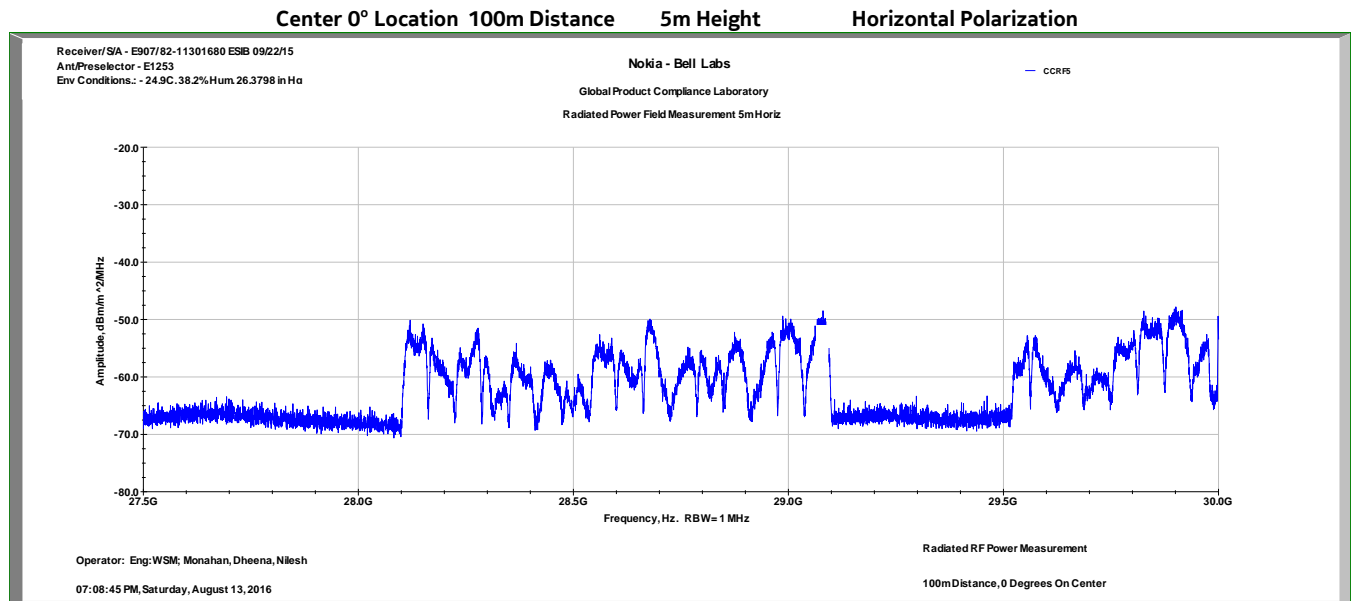
### 3.5.3 Site Measurement Details

- Tested: August 13<sup>th</sup>, 2016.
- Four active FSS earth station antennas on site out of which one was active in the frequency range.
- Active transmissions from 28.1-29.1 GHz and 29.5-30.0 GHz
- The antenna was circularly polarized.
  - Expected measured V & H values are 3dB down from LHP and RHP
- All measurements were made with ideal clear sky weather overhead.
  - Ideal clear sky weather in the direction of transmission.
- Measurements were made at 0°, 90° CW and 180° with respect to center antenna.
- The 0° measurements were made at distances of 100m and 200m.
  - The measurements at 200m distance had an elevation gain of 24ft (7.32m).
- The 90° left measurements were made at 100m.
- The 180° measurements were made at 140m.
- All measurements were made at 2m, 4.5m, 5m and 6m measurement antenna heights.



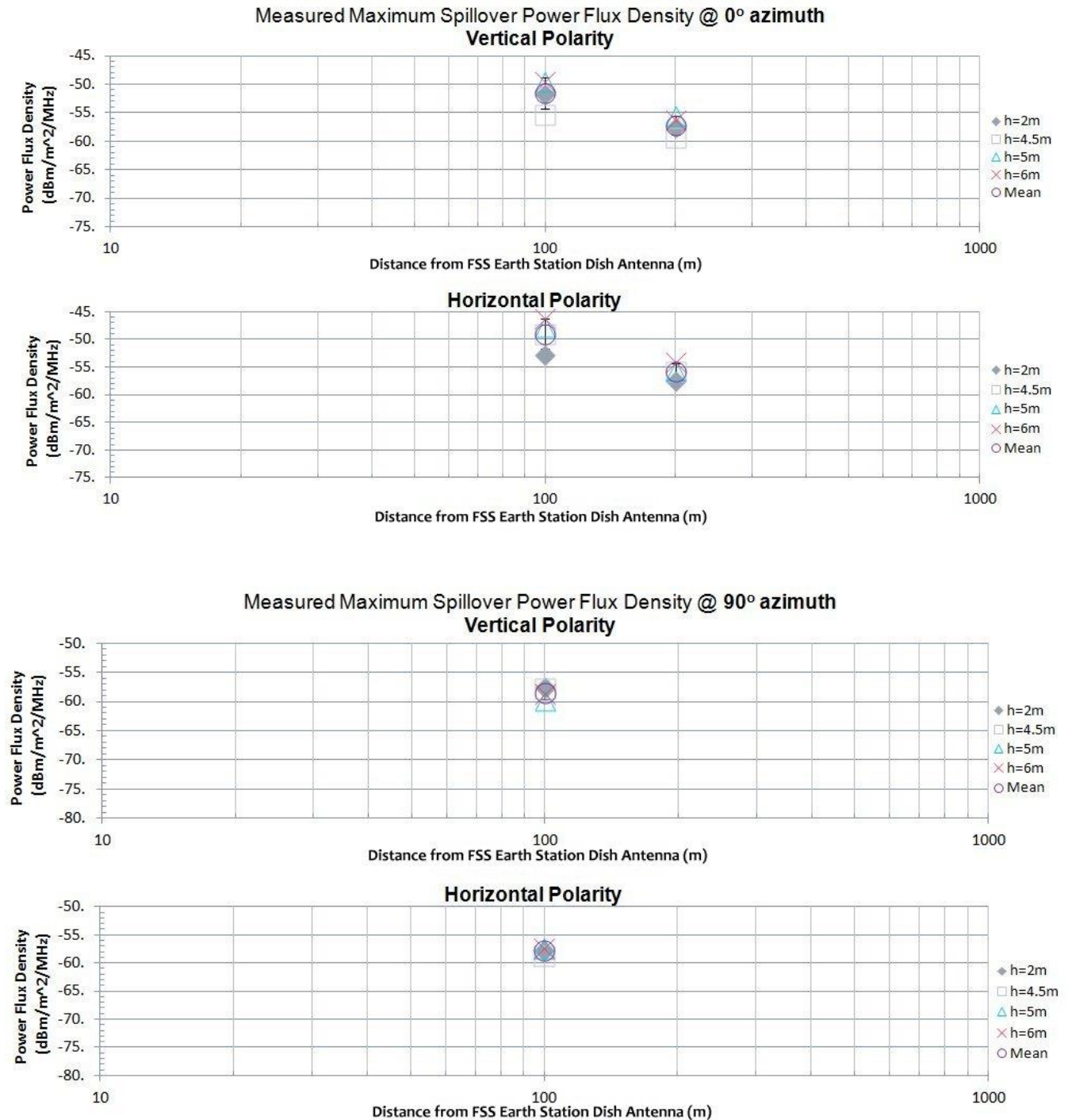
### 3.5.4 Measured Data Plots

#### 3.5.4.1 Sample EMI Receiver Scans

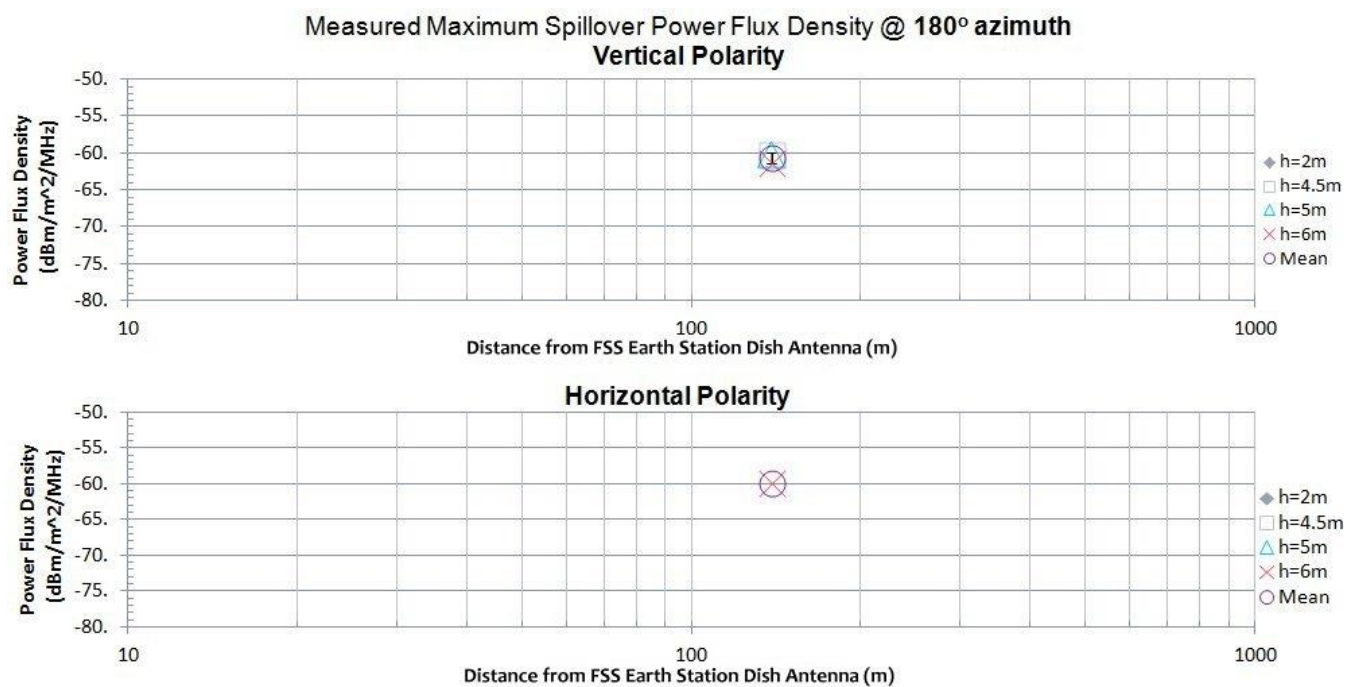




### 3.5.4.2 Effect of Distance and Receive Antenna Height on Measured Power Flux Density







### 3.5.5 Site Photos



## 4. Conclusions

The test results have qualitatively and quantitatively increased our understanding of the RF environment around the FSS earth station sites. Measurement data from site to site was consistent in showing the same data trends. In general, the emissions were lower as the measurement antenna was moved farther away horizontally from the source and higher as the measurement antenna was moved vertically up. This was expected and is supported by the simulation.

AT&T, Nokia, Samsung, T-Mobile, and Verizon (collectively, the “Joint Filers”), in a joint filing indicate that interference from existing transmit FSS earth stations into 5G networks can be controlled by limiting the PFD at 10 meters above ground level to  $-77.6 \text{ dBm/m}^2/\text{MHz}$  at a distance of 200 meters<sup>1</sup>.

Based on the measured data, it can be concluded that the emission levels are higher and impact a greater angular area as compared to the information previously shared by the “Joint Filers” with the FCC.

The measured levels were higher than expected in front of the dish and were typically 20 to 30 dB above the  $-77.6 \text{ dBm/m}^2/\text{MHz}$  at the 200 meter distance as requested by the “Joint Filers” to protect 5G systems from FSS earth stations interference. The PFD levels measured in the vertical plane were typically 1 to 2 dB higher than the Horizontal.

The measured levels to the sides and to the rear of the sites were much higher than expected. It was also observed that there was no roll-off detected as a function of the azimuth angle as suggested by the Industry Association (SIA) in the Joint Filers’ letter.

There was relatively equal levels of power flux density (PFD) measured at all angles. In general there was only about a 10 dB reduction in the PFD that was detected at  $22.5^\circ$ ,  $90^\circ$ ,  $120^\circ$  and  $180^\circ$  as compared to that measured at  $0^\circ$ . For example if the measurement for 100 meters at  $0^\circ$  was  $-48 \text{ dBm/m}^2/\text{MHz}$  then the level measured at 100 meters /  $90^\circ$  angle was typically  $-58 \text{ dBm/m}^2/\text{MHz}$ . These levels were well beyond what could have been expected in the way of spillover from the feed structure and the front of the dish.

Specifically, the following conclusion can be drawn:

The source(s) of the side and rear emissions are more likely due to transmitter/ transmit path leakage than spillover. (It is not unusual for transmitters to leak energy at their transmit frequency. This is especially true over time as the performance of shielding interfaces degrade with environmental corrosion.)

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<sup>1</sup> See AT&T, Nokia, Samsung, T-Mobile, and Verizon May 6, *Ex Parte*.